Gamma-Ray Large Area Space Telescope (GLAST)

Spacecraft Performance Specification Draft Version 0.1a

July 14, 2000

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List of Acronyms

AOS	Advanced Orbiting System
BER	Bit Error Rate
C&D H	Command and Data Handling
C/R	Command/Response
CCSDS	Consultative Committee for Space Data Systems
COP	Command Operating Protocol
ELV	Expendable Launch Vehicle
EMC	Electro-Magnetic Compatibility
GEVS-SE	General Environmental Verification Specification for STS & ELV Payloads
GLAST	Gamma-ray Large Area Space Telescope
GN	Ground Network
GPS	Global Positioning System
GSE	Ground Support Equipment
IRD	Interface Requirements Document
MSS	Mission System Specification
PAF	Payload Adapter Fitting
SC	Space Craft
SI	Science Instrument
SN	Space Network
STS	Space Transportation System
TBD	To Be Determined
TBR	To Be Resolved
TDRSS	Tracking and Data Relay Satellite System
V	Volt
VCDU	Virtual Channel Data Unit
W	Watt

1 Introduction

This specification captures the performance functionality and contains the key performance requirements for the GLAST spacecraft. Although most of these are the top-level, implementation-independent requirements to which the spacecraft is to be designed, there are also some design-directed requirements, such as the type of data bus, and certain features that we are looking for in a spacecraft for the GLAST mission.

Some of the functions in the following subsections are deliberately not allocated to a subsystem. The subsystems themselves are only loosely defined. This specification tries to focus on the essential functions, so that the spacecraft vendor is not required to have a specific partitioning for the proposed system. It is left to the vendor's design specification to perform the allocation of functions according their definition of subsystems.

The requirements in this specification flow down from the Science Requirements Document and the Mission System Specification (MSS), which contains the system-level requirements on the GLAST Observatory. The MSS also contains the mission requirements, such as mission lifetime, orbit, etc., that apply to all system elements of GLAST, including the Spacecraft.

Instrument interfaces for the Spacecraft are contained in the SI-SC Interface Requirements Document (SI-SC IRD). The IRD also contains the launch vehicle interfaces and the space environment estimates for instruments and spacecraft.

1.1 Spacecraft System

The spacecraft consists of all of the components needed to provide host services to the scientific instruments. Together, the spacecraft and the science instruments make up the GLAST observatory

1.1.1 System Description

A functional description of the spacecraft is presented in this subsection. For the sake of discussion, it is necessary to collect closely related functions into "systems". However, this is not intended to imply that the spacecraft is partitioned into subsystems, as this partitioning may be determined by the builder's organizational structure or legacy hardware. A functional block diagram of the spacecraft is shown in Figure 1-1.

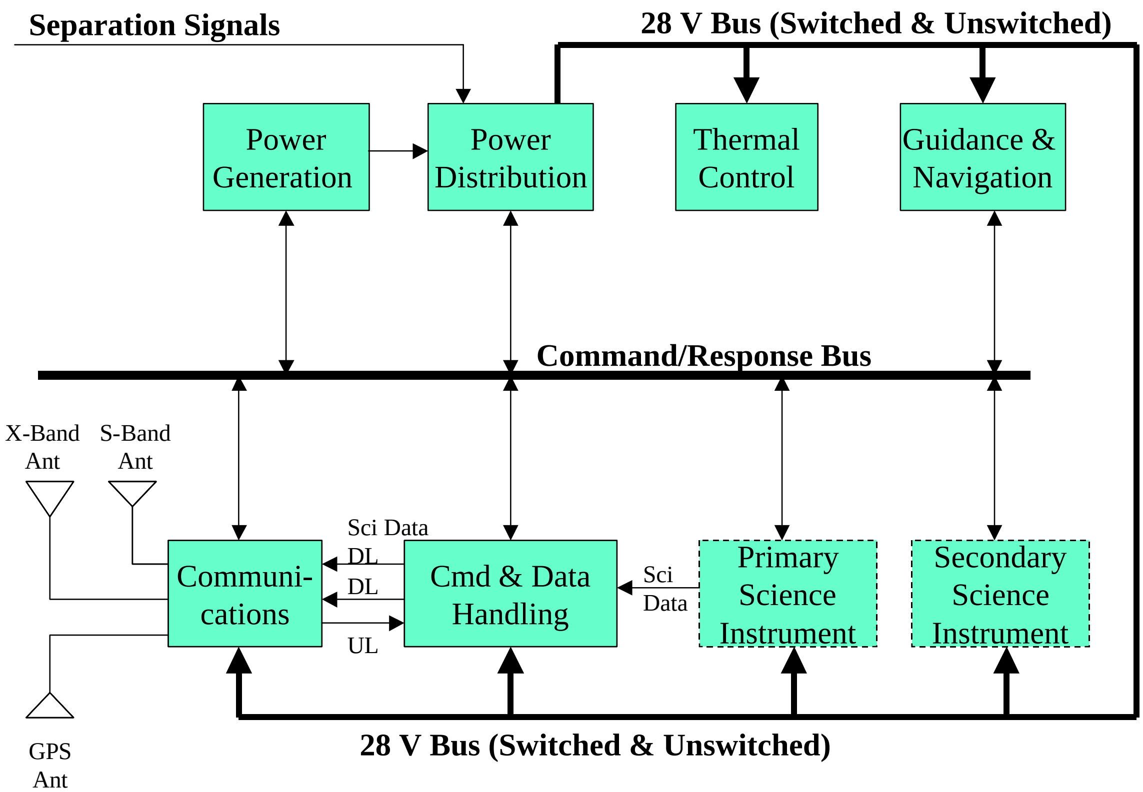

Figure 1-1Functional Block Diagram of the Spacecraft

A few notes are in order. First, there are some underlying components that do not appear on the functional diagram, viz., structure and flight software. Second, although the instruments are not part of the spacecraft system, as it is defined for GLAST, they are shown on the diagram to complete the set of components receiving spacecraft services.
The mechanical system performs the function of providing a mounting platform for all of the spacecraft components and the science instruments. It is also responsible for providing clear fields of view and for maintaining alignment, as required by some spacecraft components and science instruments.
The power generation function converts solar energy to electrical charge, stores, and regulates it for the operation of spacecraft and instrument components. It is considered to include solar arrays, batteries, battery charge control and conditioning circuitry, power regulation electronics, and instrumentation for monitoring state of charge, temperatures, etc. Power distribution includes the generation of the different power buses that are needed and the distribution of various services. It also includes fault isolation (fusing, circuit breakers, diode OR-ing) for these services and the monitoring of currents and voltages for the individual services. The grounding and shielding configuration for the spacecraft is also part of the power distribution system.
The thermal control system performs the function of maintaining the spacecraft component temperatures within safe operating and non-operating ranges. It also maintains interface temperatures for the instruments, and it may be called upon to shed a portion of the instrument heat load. Thermal control includes heaters, thermostats, certain temperature sensors, heat pipes, radiating surfaces, insulation, and thermal

isolators, as needed to control the temperatures of the various spacecraft components and instrument interfaces.

The GNC system executes the observing control modes of the observatory and provides a safe mode. The GNC system includes all of the sensors and actuators that are needed to maintain control authority in all modes. This system is self-monitoring and has the capability for detecting and correcting faults within the control system. The GNC system is also self-contained in the sense that it performs its own orbit determination on board from GPS position data.

The command and data handling(C&DH) system distributes commands to and receives data from spacecraft components and science instruments via a command/response bus. The C&DH system interfaces with the S-band communications system for command uplinks and telemetry downlinks. In addition, the C&DH system provides a high-rate interface to the primary science instrument for receiving science data. The C&DH system provides bulk data storage for this data, which is output nominally once a day, via a high rate interface with the communication system.

The communications system provides omni-directional communications for S-band traffic, which may flow through TDRSS as well as through a direct ground station. Alert messages travel bidirectionally through TDRSS, using its demand access service. The high-rate science data is downlinked via a gimbaled X-band antenna to a direct ground station.

1.1.2 System Interfaces

System interfaces for the spacecraft are shown in Figure 1-2. These are the external interfaces for the spacecraft that are or will be specified in different interface specification documents. The builder of the spacecraft will specify internal interfaces between spacecraft subsystems, as well as those between the spacecraft and its GSE.

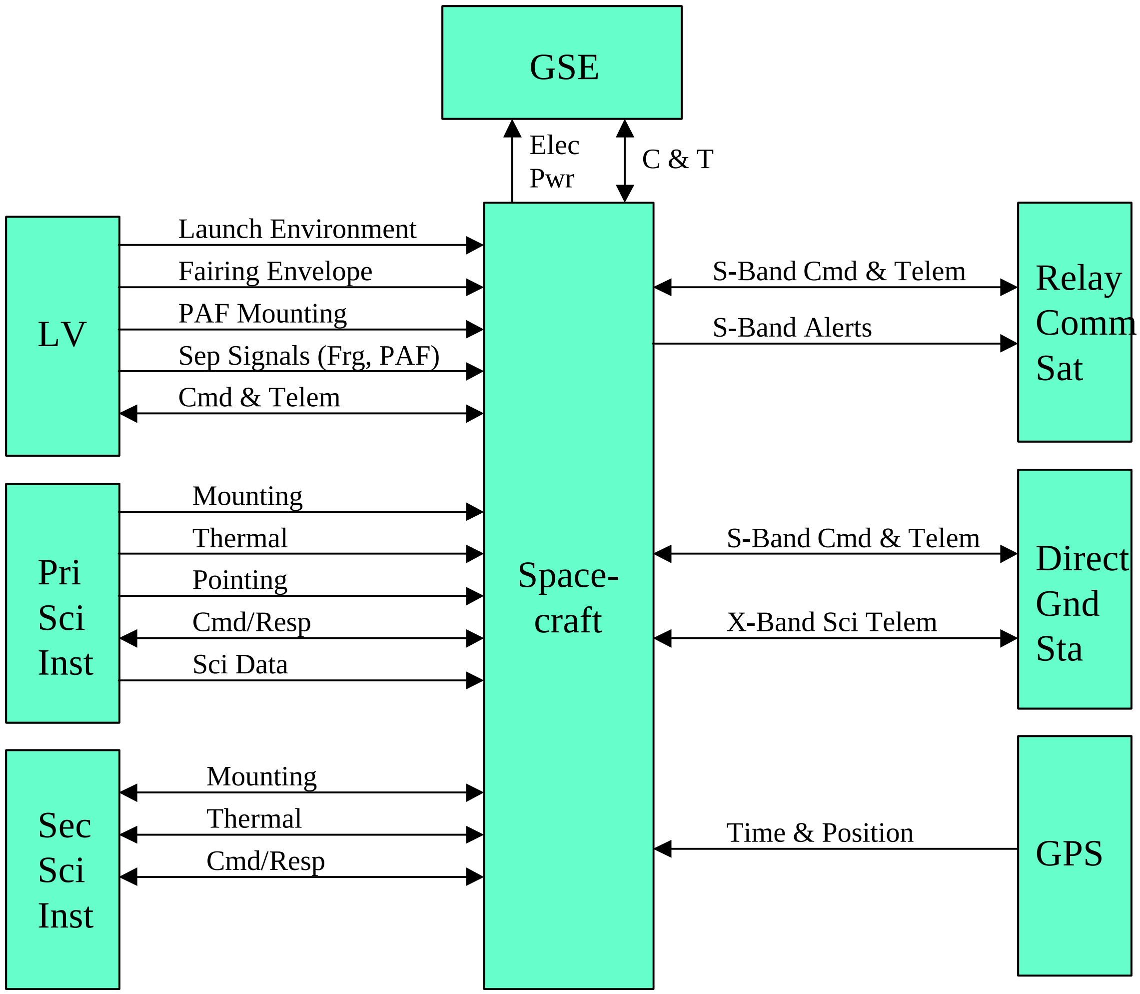

Figure 1-2 Spacecraft Interfaces

2 Applicable Documents

2.1 Project Documents

GLAST Science Requirements Document, July 9, 1999
GLAST Mission System Specification, Draft Version 0.2, May 25, 1999
GLAST SI-SC Interface Requirements Document, Draft Version 0.2, April 14, 1999

2.2 Reference Documents

CCSDS 701.0–B–2, “Recommendation for Space Data Systems Standards. Advanced Orbiting Systems, Networks, and Data Links: Architectural Specification.” CCSDS Recommendation, Blue Book.
CCSDS 101.0–B–3, “Recommendation for Space Data Systems Standards. Telemetry Channel Coding.” CCSDS Recommendation, Blue Book
CCSDS 102.0–B–4, “Recommendation for Space Data Systems Standards. Packet Telemetry.” CCSDS Recommendation, Blue Book.
CCSDS 201.0–B–2, “Recommendation for Space Data Systems Standards. Telecommand, Part 1: Channel Service.” CCSDS Recommendation, Blue Book.
CCSDS 202.0–B–2, “Recommendation for Space Data Systems Standards. Telecommand, Part 2: Data Routing Service.” CCSDS Recommendation, Blue Book.
CCSDS 202.1–B–1, “Recommendation for Space Data Systems Standards. Telecommand, Part 2.1: Command Operation Procedures.” CCSDS Recommendation, Blue Book.
Mil-STD 461E, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
GEVS-SE Rev A, General Environmental Verification Specification for STS & ELV Payloads, Subsystems, and Components. http://arioch.gsfc.nasa.gov/302/gevs-se/toc.htm
SAE AS1773, Fiber Optics Mechanization of a Digital Time Division Command/Response Multiplex Data Bus, Society of Automotive Engineers, September, 1995
Mil-STD-1553B, Aircraft Internal Time Division Command/Response Multiplex Data Bus, 21 September, 1978
NASA HDBK 4001, Electrical Grounding Architecture for Unmanned Spacecraft, February 17, 1998
Delta II Payload Planners Guide http://www.boeing.com/defense-space/space/delta2/guide/ijndex.htm

3 Requirements

The primary requirement for the spacecraft bus is to provide host services for the scientific instruments and for its own subsystems. This section provides the top-level functional and performance requirements for the spacecraft.

3.1.1 System Requirements

3.1.2 Instrument Accommodation

The spacecraft shall accommodate 1 primary instrument and 1 secondary instrument.

3.1.2.1 Operational Lifetime

The spacecraft operational lifetime shall be 5 years, with a goal of 10 years, as specified in the MSS.

3.1.2.2 Orbit

The spacecraft system shall operate in the GLAST orbit of 28.5 degrees (TBR) at 550 km (TBR).
The spacecraft shall maintain orbit eccentricity of less than 0.001 (TBR).

3.1.3 Units of Measurement

The spacecraft shall observe the current NASA policy directive, NPD 8010.2B.
Metric units shall be used in all design calculations. English units may be used for mechanical fabrication.

3.1.4 Data Quality

The spacecraft shall maintain the data quality of the science data stream to $< 10^{-10}$ undetected bit error rate.

3.1.4.1 Launch Vehicle

The spacecraft system shall be designed to meet payload requirements for the Delta II 7920-10.

3.1.4.2 Radiation

The spacecraft system shall meet radiation and environmental constraints specified in the MSS.

3.1.4.3 Reliability

All spacecraft systems shall be single fault tolerant, except for certain components, such as batteries and drive mechanisms for X-band antenna and for solar arrays.
Potential failure of these components shall be rendered non-credible.

3.1.4.4 Electromagnetic Compatibility

The spacecraft shall be consistent with the Electromagnetic Compatibility (EMC) guidelines defined in the General Environmental Verification Specification for STS and ELV Payloads, Subsystems, and Components (GEVS-SE) and the Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment (MIL-STD-461E).
Detailed requirements shall be documented in the GLAST EMC Requirements document.
All spacecraft components and science instruments shall conform individually to Mil Std 461E to ensure mutual electromagnetic compatibility.
Electromagnetic compatibility shall be preserved in the interconnected system of spacecraft components and science instruments in all operating modes.

3.1.5 Mass Allocations

The spacecraft mass shall not exceed 1100 kg.
The spacecraft system mass allocations are as follows:
The mechanical subsystem mass shall not exceed TBD kg.
The electrical power generation and distribution subsystem mass shall not exceed TBD kg.
The GN&C subsystem mass shall not exceed TBD kg.
The C&DH subsystem mass shall not exceed TBD kg.
The communications subsystem mass shall not exceed TBD kg.
the thermal subsystem mass shall not exceed TBD kg.
the ACS subsystem mass shall not exceed TBD kg.
The spacecraft mass reserve shall be not less than TBD kg.

3.2 Mechanical System

The mechanical system consists of all primary and secondary structure for the spacecraft bus, deployment assemblies and mechanisms for solar arrays and X-band antenna, and interface structures between the spacecraft bus and the scientific instruments.

3.2.1 Mounting Platform

The spacecraft bus structure shall provide a mounting platform for spacecraft bus components and for science instruments.
The bus structure shall accommodate the location requirements of the bus components while meeting the launch vehicle constraints.

3.2.2 Constraints

The mechanical system shall meet the constraints of the Delta II 7920-10 launch vehicle.
The observatory shall meet the payload requirements of the Delta II 7920-10 launch vehicle with the 6915 PAF and 3-meter fairing. The CG requirements shall comply with the Delta II Payload Planners Guide.
The spacecraft will be designed to meet Delta 7920-10 launch loads.
The spacecraft envelope including solar arrays shall be < 3m diameter.

3.2.3 Interfaces

The mechanical system shall accommodate all instrument interface mechanical requirements as specified in the SI-SC IRD.
The mechanical system shall preserve the fields of view for science instruments as defined in the SI-SC IRD.
The mechanical system shall ensure alignment between bus-mounted star tracker and Z-axis of primary instrument as specified in the SI-SC IRD.

3.3 Thermal Control System

The thermal control system consists of all temperature monitoring and control hardware for the spacecraft bus and the interfaces to the scientific instruments. It includes thermostats, heaters, heat pipes, insulation, surface finishes and coatings, and radiating surfaces.

3.3.1 Control Function

The thermal control system shall provide thermal control for all spacecraft bus temperature-sensitive components for all operating modes and GN&C attitudes.

3.3.2 Component Temperatures

The thermal control system shall maintain temperatures of spacecraft bus components within their allowable ranges.

3.3.3 Interfaces

The thermal control system shall accommodate all instrument interface thermal requirements as specified in the SI-SC IRD.

3.4 Guidance and Navigation Control System

3.4.1 General Requirements

The guidance and navigation control system (GNC) shall provide 3-axis, zero-momentum stabilized pointing control for the observatory in all modes of operation.
Observatory pointing shall be sky referenced in both survey and pointed observation modes.
The GNC system shall meet its performance requirements while performing continuous momentum management
The GNC system shall meet its performance requirements while in the presence of solar array and gimbaled antenna disturbances.
The GNC system shall be hardware redundant at the component level with the following exceptions. Star trackers may employ 3 for 2 redundancy, and reaction wheels may employ 4 for 3 redundancy.
The GNC system shall include a hot-standby, hardware-backup control system.

3.4.2 Initial Orbit Acquisition

The GNC system shall perform initial orbit acquisition (null tip-off rates, acquire sun, acquire sky referenced orbit) within 3 hours (TBR) for worst-case tip-off rates.

3.4.3 Safe Mode

The GNC system shall provide a safe mode with sun-referenced inertial hold and sun-pointed solar arrays.
Safe mode shall be commandable via the command/response bus.
Upon entering safe mode, the GNC system shall generate a safe mode alert message for transmission to the ground.

3.4.4 Fault Detection and Correction

The GNC system shall perform on-board fault detection and correction for time-critical attitude control functions where faults will cause damage or loss of control if not corrected immediately. Typically, this will involve several levels of response, 1) retries, such as for sensor data acquisition, 2) one-time redundancy switch of component, 3) switch to backup control system, 4) transition to safe mode.

3.4.5 Orbit Determination

The GNC system shall perform on-board orbit determination using GPS data.
The uncertainty in orbit position shall be less than 1 km.

3.4.6 Control Accuracy

The GNC system shall maintain attitude control to within 40 arcminutes, 1σ diameter, in both survey and pointed observation modes.

3.4.7 Pointing Knowledge

The GNC system shall determine pointing knowledge on board to within 10 arcseconds, 1σ, in both survey and pointed observation modes, except for offset slews and repointing slews.
The GNC system shall determine pointing knowledge to within TBD arcseconds, 1σ, for offset slews in sky survey mode and during repointing slews in both sky survey mode and pointed observation mode.

3.4.8 Pointing Constraints

At present, the GNC system is not required to autonomously observe any pointing constraints. Any pointing constraints, such as for solar arrays, X-band antenna, and star trackers, will be met through target selection on the ground

3.4.9 Observatory Pointing Direction

The GNC system shall generate time-tagged pointing directions in J2000 coordinates for both primary and secondary instruments at the rate of the control loop. This rate is expected to be approximately 10 Hz and will be determined by the update rate of the selected star tracker.

3.4.10 Sky Survey Control Mode

The Z-axis of the observatory shall be controlled to rotate continuously about the orbit normal.
The GNC system shall have the capability to implement a commandable roll offset of the Z-axis with respect to the plane of the orbit.
Offsets shall range from 0 to 60 degrees (TBR) above and below the plane of the orbit.
Entry to and exit from this mode shall be commanded via the command/response bus.
The GNC system shall switch to the pointed observation mode upon receipt of a valid pointing command via the command/response bus.

3.4.11 Pointed Observation Control Mode

The GNC system will execute pointing commands received in real time via the command uplink, pointing commands activated from C&DH command storage, and enabled pointing commands generated by the secondary science instrument.
The GNC system shall point the Z-axis of the observatory to a commanded celestial target and remain pointed on that target until recommanded.
As a goal, the GNC system shall have the capability to point the Z-axis of the observatory in any direction at any time. (Not all targets will be available at any given time if the solar array drive mechanisms are not capable of $\pm 180^{o}$ of rotation.)

3.4.12 Yaw Steering

The GNC system shall utilize yaw steering (rotation about the Z axis) in conjunction with solar array rotation to maintain solar arrays normal to sun line during the daylight part of orbit for both sky survey mode and pointed observation mode. Yaw steering will be used continuously in sky survey mode. It is necessary only during target acquisition in pointed observation mode.

3.5 Power System

The power system is composed of two major parts, power generation and power distribution.

3.5.1 Power Generation System

3.5.1.1 Generation Function

The power generation system shall generate and maintain electrical energy to supply power all spacecraft components and science instruments during the operational life of the mission.

3.5.1.2 Power Capability

The power generation system shall have the capability of generating a minimum of 1200 W, orbit averaged, throughout the operational life of the mission.

3.5.1.3 Bus Voltage

The power generation system shall maintain power bus voltage at 28V ± 6V dc.

3.5.2 Power Distribution

3.5.2.1 Power Services

All power distribution services shall be dual redundant.

3.5.2.1.1 Science Instrument Service

The power distribution system shall provide switched power services to science instruments.

3.5.2.1.2 Spacecraft Services

The power distribution system shall provide power services to spacecraft components. Both switched and unswitched power shall be provided.
The power distribution system shall provide a redundant pyro bus that is separate from other power services.

3.5.2.2 Grounding Configuration

The primary power system shall be grounded to the bus structure at a single point.

3.6 Electrical System

3.6.1.1 Separation

The electrical system shall detect separation events to initiate deployments and to power up spacecraft components as necessary.

3.6.1.2 Deployment

The electrical system shall provide dual-redundant, sequenced pyro firing.

3.6.1.3 Time Distribution

The electrical system shall provide hard wire distribution of the pulse-per-second time signal.
The accuracy of the GPS Standard Positioning Service shall be preserved to +/- .5 microseconds.

3.7 Command, Data Handling, and Telemetry

3.7.1 System Requirements

3.7.1.1 Coordination and Control

The C&DH system shall provide the capabilities to coordinate and control the operation of spacecraft subsystems, spacecraft components, and science instruments.

3.7.1.2 On-board Communications

The C&DH system shall provide on-board messaging communications between spacecraft components and between spacecraft and science instruments.

The C&DH system shall use an AS-1773 master-slave command/response (C/R) bus. All data transferred over the AS-1773 bus shall be compliant with MIL-STD 1553B message and protocol definitions.

3.7.2 Commanding

All uplink commands and memory load formats shall comply with CCSDS 210.0-b-2: Telecommand Part 1 Channel Service, Blue Book.

3.7.2.1 Command Decoding

The C&DH system shall decode S-band uplink commands at up to 4 kbps using CCSDS COP protocol.

3.7.2.2 Real Time Commands

The C&DH system shall process real time commands at 2 kbps Ground Network (GN) and 4 kbps Space Network (SN).

3.7.2.3 Stored Commands

The C&DH system shall provide 256 kbytes (TBR) command storage. Stored-command driven operations are 1) pointed observations for 1-3 weeks, and 2) South Atlantic Anomaly protection commands for the primary science instrument.
The C&DH system shall process and execute time-tagged stored commands.

3.7.3 Data Handling

3.7.3.1 Data Acquisition

3.7.3.1.1 Science Data Interface

The C&DH system shall acquire science source data packets from the primary science instrument via a dedicated data bus.
C&DH shall provide a dedicated Fiber Optic Data Bus (FODB) IEE-1393 for high-rate transfer of science source data packets.
The C&DH shall acquire science source data packets from the secondary science instrument via the C/R data bus.
The C&DH system shall input these source data packets to bulk storage at the rates specified in the SI-SC IRD.

3.7.3.1.2 Housekeeping Data

The C&DH system shall acquire primary instrument housekeeping data in source data packets via the dedicated high-rate bus.
The C&DH system shall acquire secondary instrument housekeeping data in source data packets via the C/R bus.
The C&DH system shall acquire spacecraft housekeeping data via the C/R bus.
Pointing direction data shall be included in the spacecraft housekeeping data.
The C&DH system shall packetize and store housekeeping data.

3.7.3.1.3 GPS Data

The C&DH system shall acquire time and position data from GPS at the GPS update rate. The C&DH system shall forward GPS position data to the GNC system.

3.7.3.1.4 Alert Messages

Upon receipt of an alert message from the secondary science instrument, the C&DH system shall format and initiate the transmission of alert messages within 1 millisecond.

3.7.3.2 Time Distribution

3.7.3.2.1 Mission Elapsed Time

The C&DH shall generate and distribute mission elapsed time in the ancillary data packet.

3.7.3.2.2 Pulse-per-Second

The C&DH shall distribute a pulse-per-second signal, via an RS-422 (TBR) bus, to the primary and secondary instruments.
The C&DH pulse per second signal shall be accurate to +/- 0.5 microsecond referenced to the GPS receiver time signal.

3.7.3.2.3 Universal Coordinated Time

The C&DH shall generate and distribute, via the C/R bus, UTC timecode messages correlated to the hard line pulse-per-second signal.

3.7.3.3 On-Board Monitoring

3.7.3.3.1 Critical Parameters

The C&DH system shall monitor the following critical spacecraft health and safety parameters against limits:
Battery state of charge
Critical component temperatures, battery temperature
Voltage and current of main power buses

3.7.3.3.2 Corrective Action

The C&DH system shall take corrective action for time-critical faults based on ground modifiable rules stored onboard.

3.7.3.3.3 Safe Mode

The C&DH system shall issue a command to the GNC system to transition to Safe Mode when mission-threatening anomalies are detected.

3.7.3.4 Ancillary Data Distribution

The C&DH system shall acquire ancillary time-tagged pointing direction data in J2000 coordinates from the GNC system.
The C&DH system shall transmit this ancillary data to the primary science instrument and to the secondary science instrument.

3.7.3.5 Bulk Data Storage

3.7.3.5.1 Amount

The C&DH system shall store up to 36 hours of science data, instrument housekeeping data, and spacecraft housekeeping data.

3.7.3.5.2 Simultaneous Operation

The C&DH system shall provide simultaneous telemetry storage and playback operation.

3.7.3.5.3 Selective Retransmissions

The C&DH system shall support selective retransmissions of stored data.

3.7.4 Telemetry

All housekeeping downlink telemetry formats shall comply with CCSDS 101.0-B-3: Telemetry Channel Coding, Blue Book.

3.7.4.1 Encoding and Framing

The C&DH system shall encode S-band downlink telemetry at up to 4 Mbps using CCSDS forward error correction encoding.
The C&DH system shall generate CCSDS AOS-compliant transfer frames for X-band downlink.

3.7.4.2 Output Rates

The C&DH system shall output data from bulk storage at 150 Mbps.
The C&DH system shall output real-time spacecraft housekeeping at up to 32 kbps.
The C&DH system shall play back spacecraft and instrument housekeeping at up to 4 Mbps.

3.7.4.3 Separate Channels

The C&DH system shall provide separate VCDU channels for housekeeping and science data.

3.8 Communications

3.8.1 S-band Coverage

The communications system shall provide omni-directional S-band coverage with respect to a geosynchronous relay satellite or to a direct ground station with > 95% (TBR) reliability from any spacecraft attitude.

3.8.2 S-band Communications

The communications system shall provide S-band communications for command and telemetry at the following data rates:
4 kbps typical TDRSS S-band, single-access service forward link
1 kbps typical TDRSS S-band, multiple-access service
2 kbps typical GN command link

32 kbps typical GN telemetry link
4 Mbps contingency GN playback downlink
Spacecraft contacts with the ground station will be commanded from the ground.

3.8.3 X-band Telemetry

The communications system shall transmit X-band data to a direct ground station via a steerable X-band antenna. The ground station will employ an 11 m antenna.
The X-band antenna shall be capable of tracking a (Wallops) ground station at 38^o latitude from any observatory attitude in the sky survey mode.
The power output of the X-band transmitter shall ensure a maximum BER of 10^{-7} (TBR) at 150 Mbps.

3.8.4 Simultaneous Operation

The communications system shall be capable of simultaneous operation of S-band and X-band communications.

3.8.5 Global Positioning System

The communications system shall acquire time and position signals from GPS satellites.